SYSTEMATICS SOLVES PROBLEMS IN AGRICULTURE AND FORESTRY[1]

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ABSTRACT

In forest and agricultural ecosystems the conspicuous elements, namely the trees, crop plants, and farm animals, form complex interactions with many less conspicuous organisms. These less conspicuous but specious organisms such as insects, fungi, nematodes, and bacteria can be beneficial, even essential, or they can be utterly devastating causing billions of dollars damage. Our present knowledge of the systematics of these less conspicuous organisms is limited. For some groups even the most elemental systematic understanding—an inventory, a checklist, a means of identification—is lacking. This paper presents examples in which systematics has contributed to solving a problem in agriculture and forestry. Our current agricultural practices reflect the systematic understanding of pest organisms that influence crop productivity. The success of efforts to discover and develop biological agents that control agricultural pests and pathogens depends on systematics. International exchange of agricultural commmodities can be enhanced or hindered by accurate or inaccurate systematic knowledge as exemplified by the recently opened market for California wheat to the People's Republic of China. Systematics is essential in directing the collection, organization, and use of vascular plant germplasm as for breeding improved crops. Forests in eastern North America have been devastated by the introduction of exotic pests and pathogens. Systematic knowledge helps to prevent such introductions. In Australia native forests threatened with extinction from an introduced weed were saved by the biological control of that weed using a fungus. Detailed systematic knowledge of both the host and pathogen allowed the safe and effective introduction of this biocontrol agent. In all the examples detailed in this paper, basic systematic knowledge was essential to solving important problems in agriculture and forestry.

Trees, crop plants, and farm animals are the most conspicuous elements in forest and agricultural ecosystems, yet these organisms have complex interactions with many less conspicuous organisms. The myriad of insects, fungi, nematodes, and bacteria that are part of these ecosystems can be beneficial, even essential, to the development of the crop, or can be utterly devastating causing billions of dollars damage. At present our knowledge of the systematics of these less conspicuous organisms is grossly limited—so limited that we often do not have even an elemental systematic understanding of their existence—an inventory, a checklist, a means of identification. These are the ecosystems upon which humanity depends for survival.

Within forestry and agriculture there is an increased interest in holistic approaches to managing the biological resources on which these industries depend. Such management strategies must allow the exploitation of biological resources to provide the immediate needs of food and fiber, but also must accommodate management approaches that minimize the impact on the environment and ensure long-term use of these resources. Such strategies include sustainable agriculture, the biological control of pest organisms, integrated pest management, and the management of forests for products other than lumber. Systematic information is the key ingredient in developing these strategies; with adequate systematic knowledge these initiatives can be successful.

This paper presents examples of problems in agriculture and forestry that have been solved by applying a systematic understanding of the organisms involved. In some cases the result was to solve short-term problems with short-term economic gain, for example, in increased international trade, while in other cases the result has been incalculable, long-term benefit, such as in the biological control of an exotic weed that was threatening to destroy an entire ecosystem. In all cases basic systematic knowledge was essential to solving the problem.

AGRICULTURE

AGRICULTURAL PRACTICES REFLECT THE SYSTEMATIC UNDERSTANDING OF PEST ORGANISMS

Agricultural practices of previous centuries included empirically integrated management of crop

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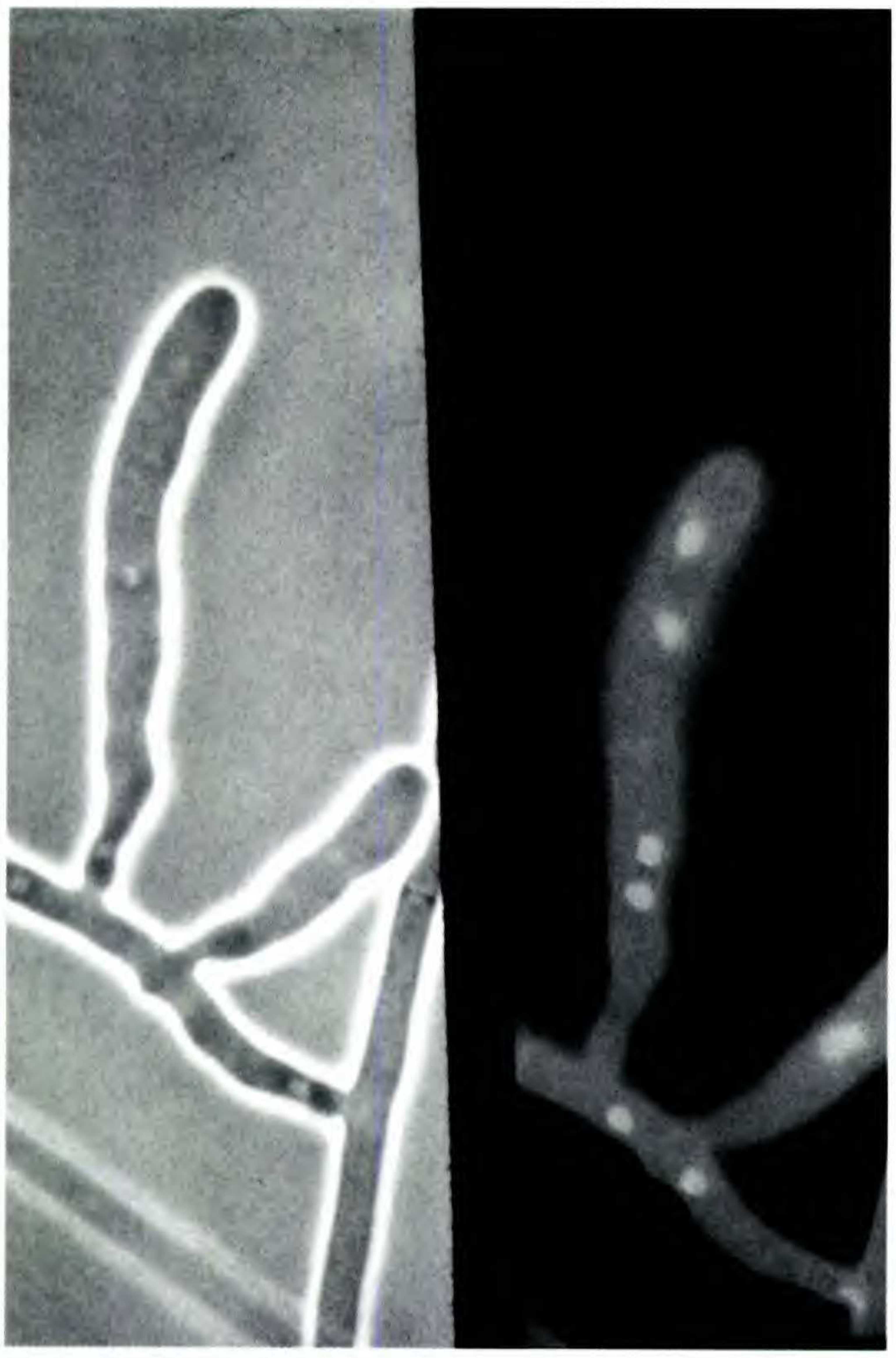

Figure 1. Binucleate hyphae of *Rhizoctonia solani* AG-4 under fluorescence (left) and dark-field microscopy (right). Photo by Marc Cubeta.

pests, often with limited success. During the last 100 years, however, these limitations on agricultural productivity have been lowered, resulting in an increased human population and demand for food. Despite spectacular success, 10–20% of all agricultural crops are still lost to pests and pathogens (Anonymous, 1993). As the need to produce more agricultural commodities increases, expectations have also increased for lower chemical input to agricultural systems and products. Knowledge of the systematics of the insects, fungi, nematodes, and microorganisms that consume a significant portion of the agricultural products provides the key to solving this dilemma.

For example, until recently the fungus commonly identified as *Rhizoctonia solani* Kühn. was believed to be a single, widespread species that occurred on almost every vascular plant and caused root rots, barepatch, wilts, diebacks, blights, and blotches (Farr et al., 1989; Parmeter, 1970). This fungal species produces almost exclusively vegetative hyphae (Fig. 1), albeit vegetative hyphae with distinctive morphology (Parmeter, 1970). In the past 20 years differences were noticed in the rarely formed sexual state, and relatedness was defined on the ability of strains to undergo anastomoses or hyphal fusion. Now the *R. solani* complex is separated into anastomosis groups, or AGs, based on this ability. Recent molecular analyses of the anastomosis groups and increased knowledge of sexual states has allowed systematists to characterize biologically meaningful species that correlate with such important parameters as host susceptibility (Ogoshi, 1987; Sneh et al., 1991). Within the entity previously referred to as *R. solani*, a number of species are now recognized, some of which are pathogens specific to particular crop plants, others are mycorrhizal with orchids, while still others can be used as biological control agents of plant pathogenic fungi (Vilgalys & Cubeta, 1994). This crucial systematic information allows plant pathologists to recognize and seek out control strategies for the species that are pathogenic on specific crops, allows orchid growers to understand the positive aspects of the presence of these fungal species, and allows biological control specialists to use these fungi in their arsenal of control agents. The systematist has made order out of chaos.

SYSTEMATICS PROVIDES THE MEANS FOR DISCOVERING AND DEVELOPING BIOLOGICAL AGENTS TO CONTROL AGRICULTURAL PESTS AND PATHOGENS

Damage to agricultural crops due to fungi, both in the field and during harvest and storage, is estimated at more than $3.5 billion in the United States (Kendrick, 1992), while the dollar value from insect damage is equal or greater. Insects, nematodes, fungi, and microorganisms constantly compete with humans for these commodities. An increasingly attractive alternative to chemical control of agricultural pest organisms is through biological control or the manipulation of a biological antagonist, often a natural enemy. One suspects that considerable biological control exists in natural systems and that the interaction and balance between organisms is extremely complex.

Fungi are being explored as biological control agents of insects, nematodes, plant pathogenic fungi, and noxious weeds. The fungi involved are not the macrofungi with which most people are familiar, that is, mushrooms, polypores, or lichens. Rather, the fungi having the greatest impact in agriculture and forestry are microscopic in size, often fast-growing, and producing many tiny reproductive structures. As a group of organisms they are vastly understudied, to the extent that at least 50% of the new species with biocontrol potential have yet to be discovered and described. Fundamental systematic information, such as species descriptions and understanding of relationships with known species, is needed.

One example in which systematic knowledge has contributed to the development of effective biological control concerns fungi used to control soilborne fungal diseases in temperate agricultural systems. Like many Ascomycetes, these fungi are most commonly encountered as asexually reproducing strains for which a sexual state may or may not be known. One of the most commonly used biocontrol strains was initially identified as *Gliocladium virens* Giddens, Foster & A. A. Foster. Although described in *Gliocladium*, this biocontrol fungus is morphologically and biologically unlike the type and other species in this genus. Using both morphological and molecular approaches, two systematists have shown that *Gliocladium virens* actually belongs in the relatively unstudied genus *Trichoderma* (Fig. 2) (Rehner & Samuels, 1994; Samuels & Rehner, 1993). Based on that conclusion, one would predict the related sexual state of this fungus would be an ascomycete in the genus *Hypocrea* (Fig. 3). Thus, strains of the closest sexually reproducing relative, *H. gelatinosa* (Tode) Fr., were tested for the production of the fungal metabolite gliotoxin. Gliotoxin is correlated with potential for biological control of fungal pathogens. Strains derived from the closely related sexual state produced as much gliotoxin as the biocontrol fungus. In addition, some of these newly discovered biocontrol strains produced their sexual states in culture, allowing conventional genetic manipulation. Thus, increased knowledge of the systematics of the *Trichoderma* complex led to the prediction and discovery of more effective strains of biological control fungi.

Unlike the above example, agricultural problems are often solved using the brushfire approach of reacting when an emergency arises, undertaking a narrow research program on the pest causing the problem, possibly finding a solution, and going on to the next agricultural brushfire. Because comprehensive systematic knowledge is not generated in solving an immediate problem, the short-term solution does not add significantly to the development of a predictive classification system. In fact, in many situations systematic analysis of a single species, removed from the context of phylogeny and biogeography, and not carefully integrated into a classification system, detracts rather than adds useful information. An example of a circumstance where comprehensive research followed a brushfire solution involved a pest in Africa. An unknown mealybug attacked cassava in West Africa (Fig. 4) and cost farmers £1.4 billion each year (Anonymous, 1986). A systematist described the species (*Phenacoccus manihoti*) as new and, based on the systematic relationship of this species with others, suggested that natural enemy exploration be undertaken in Central and South America (Matile-Ferrero, 1977). Additional specimens of a mealybug erroneously identified as *P. manihoti* were discovered in northern South America, and several of its parasites were imported to Africa. Unfortunately, none of the biological control agents were effective, and a mealybug systematist was asked to study the South American material. The systematist determined that the mealybug from northern South America actually was a second species different from *P. manihoti* described from Africa (Cox & Williams, 1981). Eventually true *P. manihoti* was located further south in South America, and effective parasites were discovered and successfully introduced into West Africa (Herren & Neuenschwander, 1991). After this brushfire was put out, the International Fund for Agricultural Development offered financial support for a study on the mealybugs of South America. A book has recently been published (Williams & Grana de Willink, 1992) that serves as a first step toward understanding the diverse mealybug fauna of the area and prepares the world for the emergence of the next devastating mealybug pest.

INTERNATIONAL EXCHANGE OF AGRICULTURAL COMMODITIES DEPENDS ON ACCURATE SYSTEMATIC INFORMATION

International exchange of agricultural commodities in the United States was valued at $24 billion for imports and $42 billion for exports in 1992, accounting for a significant portion of total domestic exports (Anonymous, 1993). Regulations governing the international exchange of agricultural and forest commodities are directed at the containment of economically damaging organisms. Thus, such exchange requires the accurate and rapid identification of both domestic and exotic pests and pathogens. Systematists provide the expertise and tools on which these identifications are made, allowing the existence of this multibillion dollar industry.

The smut fungi, Ustilaginales, cause severe diseases of important grain crops (Fig. 5). Although relatively well surveyed and described, these obligate parasites are generally considered to be host specific and are identified primarily based on teliospore characteristics. Their identification is difficult and requires taxonomic expertise, particularly

Figure 2. SEM of *Trichoderma virens*, a fungus with potential for the biological control of plant pathogenic fungi. Photo by James Plaskowitz.

if the host is unknown or misidentified. *Tilletia indica* (Mitra) Mundkur, karnal bunt of wheat, is a smut fungus that occurs in limited regions of the world (Green, 1984; Smith et al., 1992; Waller & Mordue, 1983). Extreme vigilance is required to prevent the spread of this pathogen. Recently, wheat (*Triticum aestivum* L.) imported into Canada from the United States was determined to be contaminated with *Tilletia indica*. Plant quarantine officials in both the U.S. and Canada became quite excited, and a ban on the import of wheat from the U.S. to Canada was suggested. A systematist who

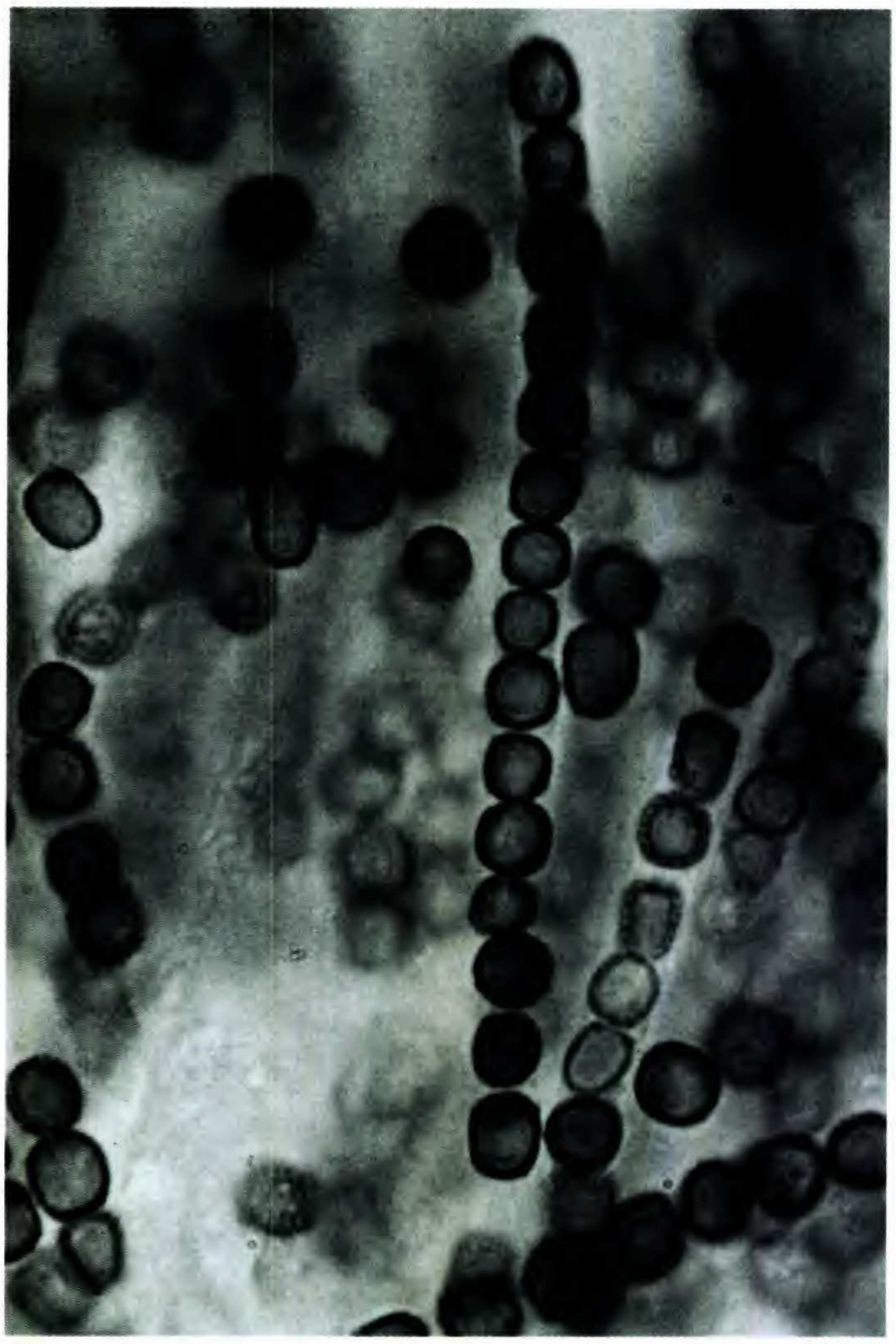

Figure 3. Asci with 16 partspores of *Hypocrea gelatinosa*, the sexual state of *Trichoderma virens*.

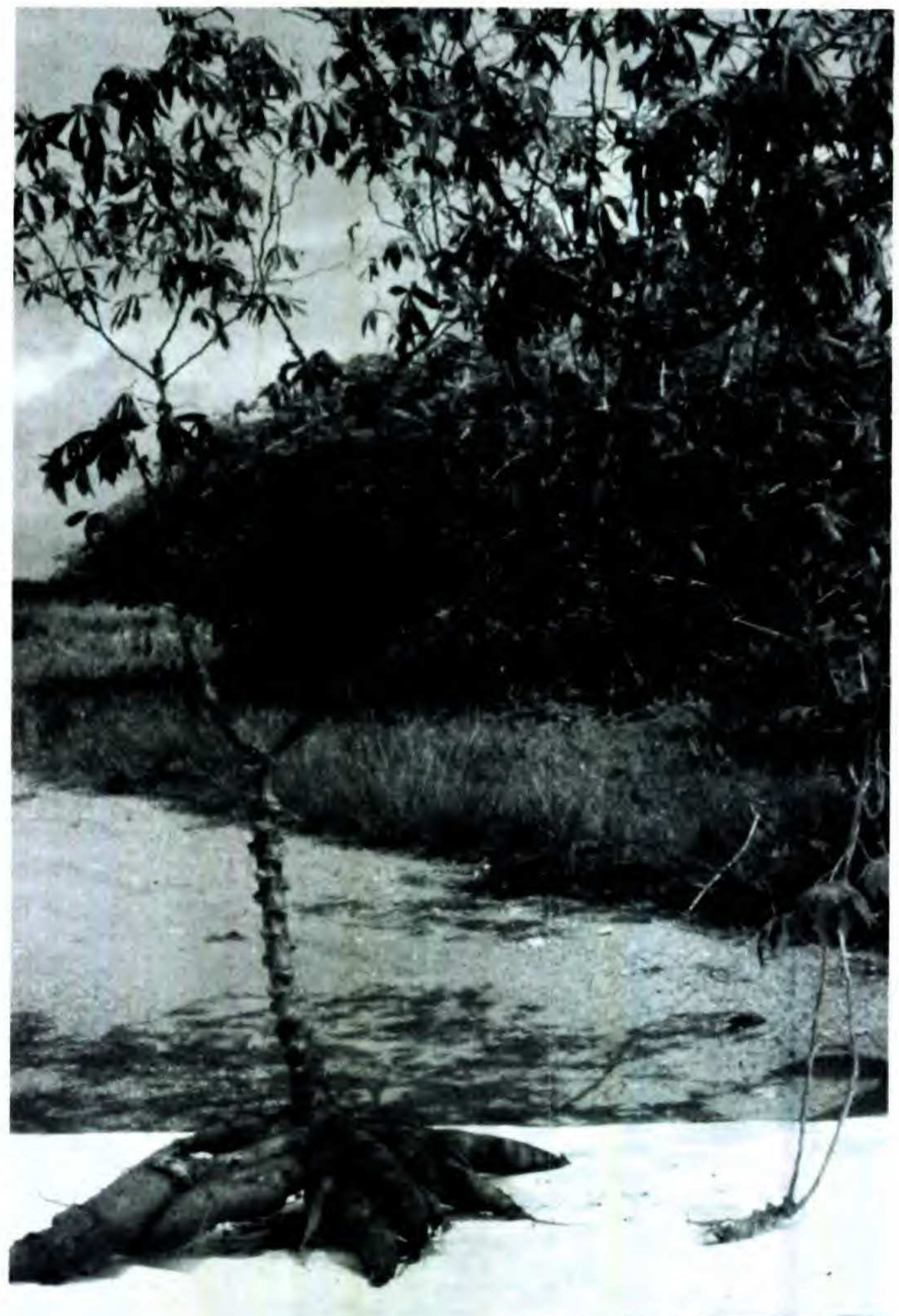

Figure 4. Cassava trees in West Africa. The tree on the right attacked by the mealybug *Phenacoccus manihoti* has not produced large, edible tubers, while the one on the left is free of mealybug attack and shows normal tuber production.

was asked to study the material correctly identified the smut as *Tilletia barclayana* (Bref.) Sacc. & Syd. This smut fungus occurs on rice and apparently contaminated the wheat when it was stored in a warehouse that had previously contained rice. This identification was eventually confirmed with isozyme analysis, and a potentially costly international incident was averted (Mary Palm, pers. comm., 1993).

Systematic knowledge of another smut fungus on wheat and the clarification of the circumstances under which it was collected have allowed the sale of wheat from California to the People's Republic of China. Export of wheat from the Pacific Northwest of the United States to the People's Republic of China has been curtailed since 1972 because of the presence of *Tilletia controversa* Kühn., dwarf bunt, a fungus not known to occur in China. A second bunt disease of wheat, common bunt or rough-spored bunt, is caused by *T. tritici* (Bjerk.) Wolff and occurs throughout the world wherever wheat is grown (Anonymous, 1990; Mordue & Waller, 1981). Differentiating teliospores of *T. tritici* from *T. controversa* is difficult to impossible because of their morphological similarity. Thus, it is important to know if dwarf bunt is present, absent, or has ever occurred in specific regions in the U.S. from which wheat might be shipped to the People's Republic of China. The wheat-growing regions of California are free of dwarf bunt except for one report of *T. controversa* (Duran & Fischer, 1956). This report curtailed the export of wheat from California to China. The report of dwarf bunt in California was based on a specimen collected [on June 30, 1917 in Jacksonville, "California"] by a U.S. Department of Agriculture plant pathologist, H. B. Humphrey. The specimen was deposited in the U.S. National Fungus Collections and was available for study. Despite intense efforts using morphological, biochemical, and molecular means, it was not possible to identify this specimen as either *T. tritici* or *T. controversa*. Since identification was not possible, a new strategy was devised that again depended on systematic facilities. All specimen label data associated with the specimens at the U.S. National Fungus Collections had previously been entered

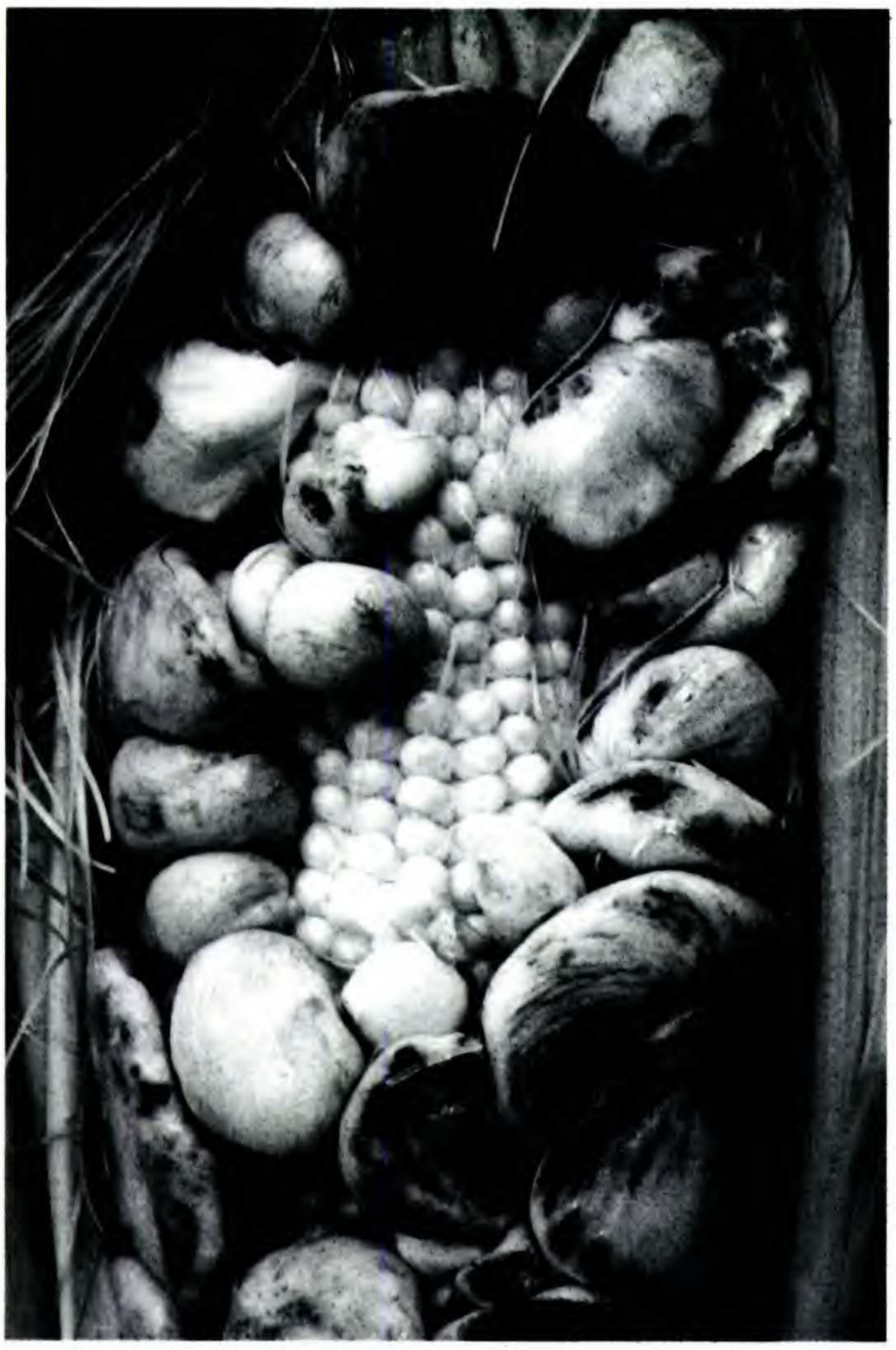

Figure 5. Corn smut fungus, *Ustilago maydis*, infecting kernels of field corn in Maryland.

into a computerized database. Using this systematic information resource, it was possible to determine the approximate route of Humphrey on his 1917 trip (Table 1). Although this database was never intended for tracking a scientific expedition, it provided the information necessary to prove that the dwarf bunt specimen was collected in Jacksonville, Oregon, not in California. This fact was confirmed by the itinerary and telegrams of H. B. Humphrey for this trip deposited and maintained at the U.S. National Archives. Using these sources of information it was proven that this dwarf bunt specimen was not collected in California (Rossman, 1994). As a consequence, the People's Republic of China has lifted the quarantine on the import of wheat from California. According to the California Wheat Commission (B. Fernandez, pers. comm.), a first shipment of California wheat to the People's Republic of China left Stockton on April 1, 1995. This first shipment of 30,000 tons is worth about $4.7 million. Solving this systematic problem has opened a multimillion dollar market.

SYSTEMATICS DIRECTS THE COLLECTION, ORGANIZATION, AND USE OF VASCULAR PLANT GERMPLASM

Humankind has always assumed that the genetic resources required to support agriculture would continue to exist in nature forever. As an indication of the importance of genetic resource preservation, Congress has recently mandated that the United States Department of Agriculture formulate a program to develop, store, and access genetic resources for all kinds of living organisms (National Research Council, 1991). The report on specifically how this could be done and how much it would cost has been presented to them. This program includes not only vascular plants and animals of obvious importance to agriculture but also fungi, insects, nematodes, and microorganisms. Congress recognizes the essential role that biological diversity plays in human existence. The problem is how to obtain, organize, preserve, and utilize the genetic resources needed to insure that future agricultural needs will be met. The critical basis for developing and utilizing genetic resources is systematic knowledge (Shands & Kirkbride, 1989).

For vascular plant germplasm in the United States, a large system of repositories exists. The U.S. National Plant Germplasm System contains 5–10% of the 250,000 vascular plant species in existence (National Research Council, 1993). Information on the over 400,000 accessions is based on the systematics of the organisms using the Germplasm Resources Information Network. Entry to accession information is through the scientific name of the species, and all communications depend on

Table 1. Route taken by H. B. Humphrey in 1917 as determined by collection data on specimens deposited in the U.S. National Fungus Collections.

Specimens collected by H. B. Humphrey in 1917 deposited in the U.S. National Fungus Collections
• June 24 1917 Campbell, Santa Clare County, California
• June 30 1917 Medford, Oregon
• June 30 1917 Jacksonville, California (actually Oregon)
• July 4 1917 Pullman, Washington
• July 9 1917 St. Paul, Minnesota

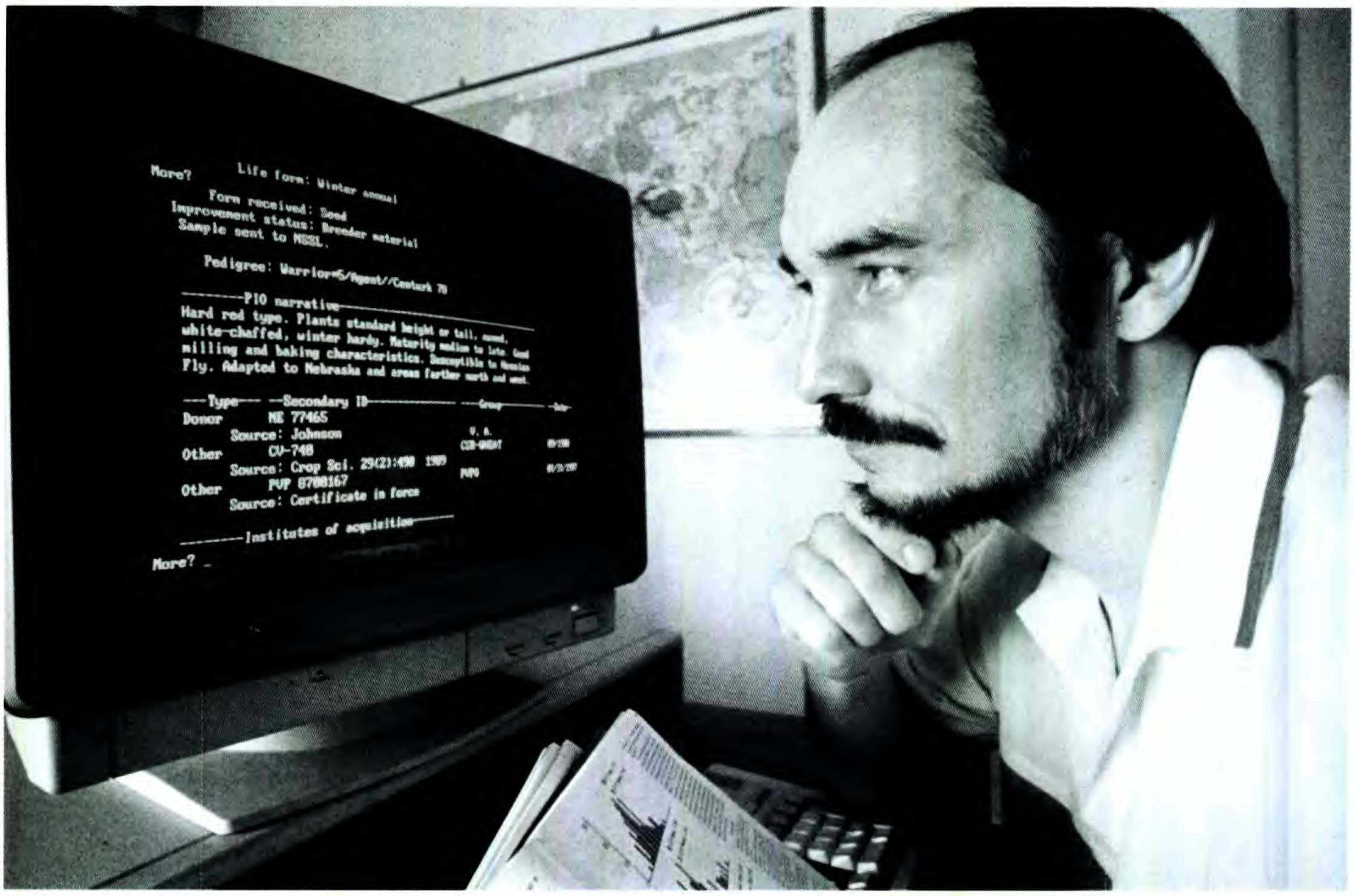

Figure 6. John Wiersema, nomenclaturalist, reviewing scientific names of vascular plants in the Germplasm Resources Information Network.

accurate nomenclature as determined by a systematist specializing in the classification of cultivated plants (Fig. 6). The systematist provides information on the relatedness and therefore the usefulness of the germplasm to its potential crop.

Repositories of vascular plant germplasm set their priorities for collecting and utilizing germplasm based on systematic knowledge of crop plants and their immediate relatives. For example, the numerous wild relatives of the cultivated potato provide the genetic basis for disease resistance that is present in today's crop. Cultivated potato is consumed worldwide and represents the fourth most important food resource (Hawkes, 1990). In the native habitat of wild potatoes ranging from the southwestern United States to south-central Chile, these relatives are often obscure weeds and are not used locally as food; indeed, some are mildly poisonous. David Spooner's research on wild potatoes (*Solanum* sect. *Petota*) illustrates the value of systematics information to plant breeding. Spooner's research has two components—-collecting for more complete germplasm representation in genebanks and systematics research to understand the species and their relationships with *Solanum* sect. *Petota*. His program, collecting in collaboration with researchers from South America, has resulted in the acquisition of more than 20 species—relatives of the cultivated potato—not present in the world's genebanks.

The world's largest collection of potato germplasm at Sturgeon Bay, Wisconsin, holds about 5000 accessions (Bamberg & Spooner, 1994) of about 170 of the 232 wild potato species recognized in the latest comprehensive taxonomic treatment of *Solanum* sect. *Petota* (Hawkes, 1990). At present, there are disagreements among taxonomists regarding the species, hypotheses of natural interspecific hybridization, and the relationships among taxa of cultivated and wild potato. The treatment previous to Hawkes (1990) recognized only 157 species, and the species boundaries and their interrelationships have yet to be reconciled (Spooner & van den Berg, 1992). Thus, Spooner's ongoing research program using a variety of tools to investigate the identity and relationships among these species is crucial for the enhancement of commercial potato products (Giannattasio & Spooner, 1994a, b; Spooner et al., 1993; Spooner & Sytsma, 1992). Because it takes 8–15 years from the initiation of a breeding program to a commercial variety release, considerable time and expense can be saved by making an initial choice of breeding material based on accurate systematic knowledge.

Forestry

Forest land in the United States occupies 737 million acres, yielding products valued at about $1 billion in 1992 (Anonymous, 1993). Other forest commodities and non-commodity uses such as recreation and watershed resources have an even greater value. Changes in the public's perception of the value of forest lands have led to a major shift in their management. This new management philosophy has resulted in older tree stands and in greater value of non-timber species. Long-term forest system management has a different set of problems than those associated with traditional forest management. While most forest managers measure physical and chemical aspects of their forest as well as monitor changes in the macrofauna and flora, they generally are unable to measure the biological diversity of the total forest biota. Knowledge of the systematics of non-timber components of forest ecosystems is essential to their sustainable maintenance.

Systematic knowledge helps prevent the introduction of exotic pests and pathogens that destroy forests

A major force in the destruction of forests, aside from harvesting of trees, has been damage inflicted by introduced forest pests and pathogens. The economic loss to timber revenues is estimated at $2 billion annually (Campbell & Schlarbaum, 1994), with a much greater loss in recreational value. The infamous American chestnut blight introduced on Asian chestnut nursery stock in 1904 has altered the landscape of the eastern deciduous forest forever (Anagnostakis, 1987). Yet nursery stock and unrefined logs are imported into the United States without thorough knowledge and understanding of the organisms associated with them (Campbell & Schlarbaum, 1994; Redlin, 1991). The fungus causing dogwood anthracnose, *Discula destructiva* Redlin (Fig. 7), was described only recently (Redlin, 1991) but its origin is still unknown because of inadequate baseline data on the fungi in the United States and the rest of the world. Its simultaneous appearance on both coasts of North America suggests that it was introduced on nursery stock (Campbell & Schlarbaum, 1994). Increased systematic knowledge of the inconspicuous organisms that occupy forests worldwide is needed to prevent additional destructive introductions.

Systematic tools for the rapid identification of potentially harmful organisms also will avert future disasters. In 1993 a ship arrived in Wilmington, North Carolina, carrying a cargo of military goods from Germany. When the ship's holds were opened, moths were seen flying from the cargo areas. Agricultural quarantine inspectors closed the holds and set the ship back out to sea. The insects appeared to be the gypsy moth but inspectors were unsure whether they were the European gypsy moth, which is established on the East Coast from an earlier introduction, or the Asian gypsy moth, which does not occur in the U.S. and is notable for its flying females. The samples were shipped to Delaware, Ohio, where systematic specialists used molecular techniques to quickly identify the specimens as the Asian gypsy moth. The ship's cargo areas were fumigated, and a trapping program around the port was initiated to eradicate the Asian gypsy moth before it could become established. Previous development of a rapid identification method by systematists had given quarantine decision makers the tools to avert the establishment of a potentially damaging exotic pest.

Decisions to allow the importation of agricultural and forestry commodities into the United States are generally based on whether a potentially damaging organism already exists in this country. Unfortunately, this assumes that these organisms are known and accurately identified in the U.S. At present only about 50% of the insects (Kosztarab & Schaefer, 1990) and 20–40% of the fungi in the U.S. have been described (Klassen, 1986). A database has been developed of reports of fungi on plants and plant products in the United States (Farr et al., 1989). This database is one of the primary resources on which the Animal and Plant Health Inspection Service depends when making decisions about entry of commodities into the United States. Previously this information was scattered and difficult or impossible for decision makers to obtain. Now with a single source of systematic information, more knowledgeable decisions can be made. In some cases this information has allowed the importation of plant products that previously were prohibited entry because of the lack of knowledge about the organisms in the United States.

Although this database is the most comprehensive account of plant-associated fungi in the world, listing 13,000 species (Farr et al., 1989), it is far from complete, particularly for fungi on non-crop plants. The fungi reported in the literature are usually those that are conspicuous or cause damage to plants of economic interest. We now know that there are potentially pathogenic fungi that live inside apparently healthy plant tissue (Carroll, 1988). Visual inspection of such plants does not detect these latent pathogenic fungal species. As an example of the inadequate knowledge of fungi in the

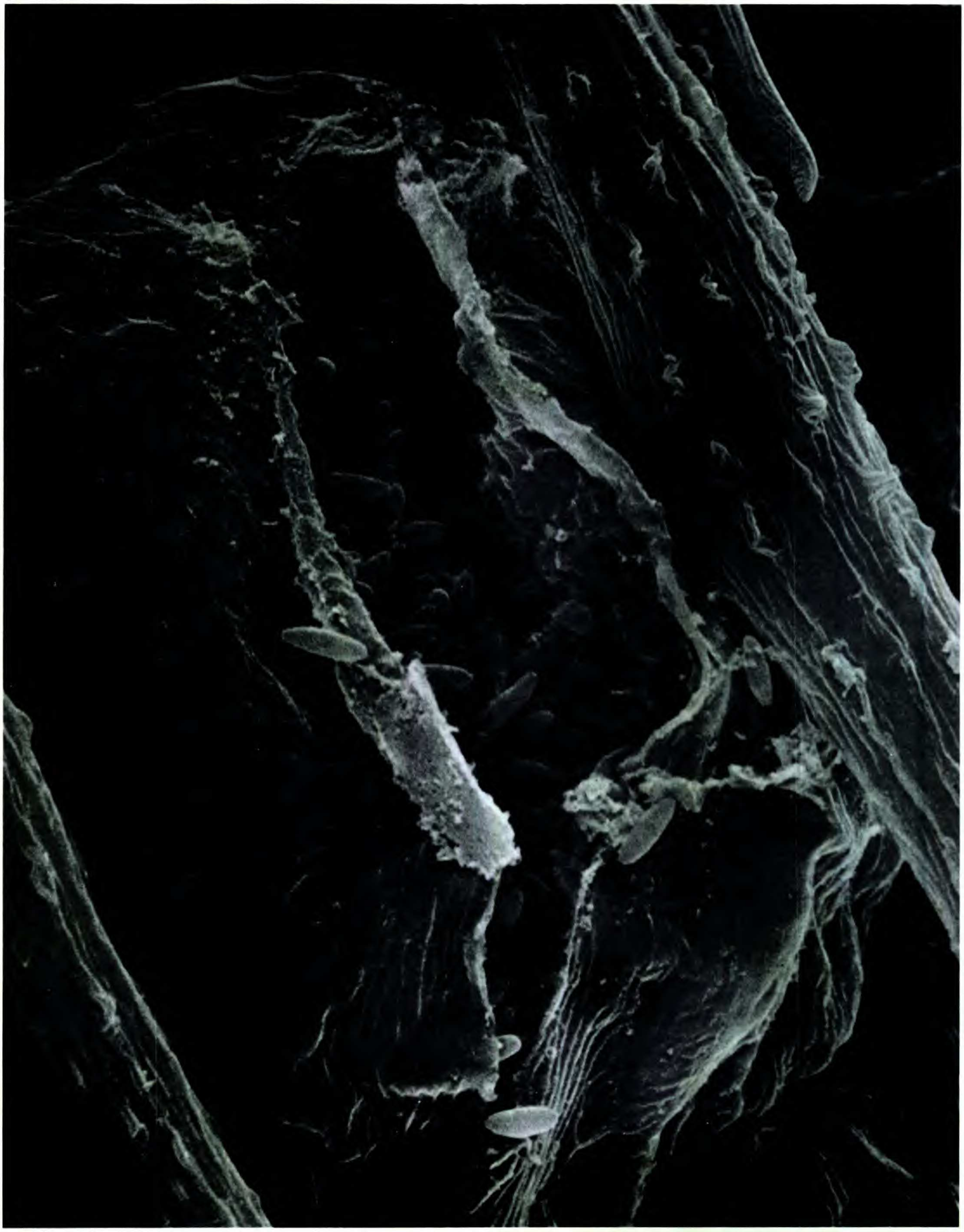

Figure 7. Conidiomata and conidia of fungus causing dogwood anthracnose, *Discula destructiva*, erumpent through leaf epidermis.

U.S., we compared from various sources the fungi known to occur on one host, *Chamaecyparis thyoides* (L.) B.S.P., Atlantic white cedar (Table 2). Although not an inconspicuous host, this tree is not of profound economic importance. In Farr et al. (1989) 40 species are listed on this host. In the U.S. National Fungus Collections, 50 species are represented, of which only 9 are included in Farr

Table 2. Fungi reported on *Chamaecyparis thyoides*, Atlantic white cedar. FOPP (Farr et al., 1989), USNFC (U.S. National Fungus Collections), Bills & Polishook (1992).

Fungi known on *Chamaecyparis thyoides*, Atlantic White Cedar	FOPP	USNFC	Bills & Polishook
FOPP	40	9	3
USNFC		41	2
Bills & Polishook			72
	40	50	77
Total number of species 153			

et al. (1989). Based on these two resources alone, 81 fungal species are known from this host. In just one study Bills & Polishook (1992) isolated 77 fungal species occurring as endophytes in living tissue of this host. Of these, only three species were listed in Farr et al. (1989), while two species were represented in the U.S. National Fungus Collections. From these three resources 153 fungal species are known on *Chamaecyparis thyoides*, of which only 40, or about 25%, are reported in Farr et al. (1989). These data suggest that by simply gathering information from our systematic collections, we can enhance the knowledge base considerably. Then, in this case, by undertaking even cursory sampling activities, we can again double the number of fungal species known from that host. This fundamental knowledge of the organisms that occur in the United States is needed to make enlightened decisions about the safety of allowing entry of agricultural and other plant commodities into this country.

SYSTEMATIC KNOWLEDGE OF HOST AND PATHOGEN IS NEEDED TO CONTROL EXOTIC ORGANISMS

Introduced organisms that threaten forest ecosystems as well as grazing lands can be controlled using biological agents. To be successful, systematic knowledge of both the biocontrol agent and target organisms is critical. For example, in northern Queensland, Australia, a noxious weed known as rubbervine, *Cryptostegia grandiflora* Roxb. ex R. Br. (Asclepiadaceae: Periplocoideae), has ruined grazing lands and threatened the native forests by completely covering the trees. Exotic to Australia, where it was intentionally introduced over a century ago to cover spoils from gold mines, this perennial, woody, climbing shrub still exists in relictual but threatened populations in its native habitat of Madagascar (Evans, 1993). To solve the weed problem in Australia, the native plant populations in Madagascar were examined for both fungus and insect natural enemies. Although insects were located, none were found to be host specific and thus were not considered safe for introduction into Australia.

A rust fungus (Uredinales) with biocontrol potential was collected by Harry C. Evans of the International Institute of Biological Control in 1987–1988. Unfortunately, this rust was considered to belong in the genus *Hemileia* Berk. & Broome, in which is also placed the notorious coffee rust fungus *H. vastatrix* Berk. & Broome. The rust pathogen of rubbervine had been described in 1914 but literally ignored for decades because of its seeming lack of economic importance. Evans (1993) undertook a systematic study of this potential biological control agent and discovered that the nuclear condition of supposed urediniospores was that of a sexually reproducing fungus, thus what appeared to be urediniospores were actually teliospores or the sexual spores of the rust. Under conditions of low humidity, such as occur in the semiarid parts of Madagascar, these prolific urediniospore-like teliospores were produced in abundance. However, with high humidity, such as in a greenhouse in the United Kingdom or as occurs only occasionally in this region of Madagascar, true teliospores are produced that eventually germinate to form a variable number of basidiospores. This rare phenomenon reveals the evolutionary history of this fungus as well as its closer relationship with another group of rusts. This rust is now placed in *Maravalia* Arthur in the Chaconiaceae, Uredinales, only distantly related to *Hemileia*.

Biological control agents must be host specific. In testing for host specificity, close relatives of *Cryptostegia grandiflora* in the Asclepidaceae were examined for susceptibility to the rust fungus. While the target plant proved to be highly susceptible, related species demonstrated a range of resistance that reflected the relationships among the host plants. For example, within the subfamily Periplocoideae of the Asclepiadaceae, the closest related genus, *Gymnanthera* R. Br., proved to be highly resistant with a response that included hyphal collapse after penetration. In another related plant species, *Finlaysonia obovata* Wall., the formation of sori was initiated but pustules did not mature (Evans & Fleureau, 1993). On two species in the subfamily, *Gonocrypta grevei* Baill. and *Cryptolepis grayi* P. I. Forst., fertile sori did develop in greenhouse tests. Further studies on ecotypes of *G. grevei* demonstrated population differences with sporulation on certain plants occurring only at saturation inoculum levels. Based on these findings, two physiological races of the rust fungus were distinguished, one adapted to *Cryptostegia*, and the other to *Gonocrypta*. This was corroborated by the field observation that rusted *Cryptostegia grandiflora* grew intertwined with healthy *Gonocrypta grevei* (Evans & Tomley, 1994). As a result of increased systematic knowledge of a rust fungus, *Maravalia cryptostegia* (Cummins) Ono, and of the host plant and its relatives, rubbervine in Australia is no longer devastating the forest ecosystem.

This success story is the result of an extremely small piece of the entire systematics puzzle; most pieces of the puzzle remain separated. If there existed a thorough systematic understanding of a majority of the rust fungi, the potential for controlling exotic weeds such as rubbervine would be increased. In some parts of the world exotic weeds threaten the extinction of more biological diversity than the threat of habitat destruction from human activity (U.S. Congress, 1993). Lack of systematic knowledge is hindering use of biological control agents to stop the destruction of endangered native habitats due to exotic weeds. Given the ability of one rust species to control a noxious weed that threatened a native forest in Australia, imagine the untapped potential for the use of fungi as biological control agents. Systematics is the key to achieving that potential.

Conclusion

Many costly problems in agriculture and forestry could be solved with increased systematic knowledge of the inconspicuous organisms that influence forest and agricultural ecosystems. Systematics provides the means to use and benefit, rather than suffer, from their biological influence. The economic payoff from using systematic knowledge to solve problems in agriculture and forestry is far greater than the cost of funding a systematics research program.

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